DESIGN AND PERFORMANCE EVALUATION OF A DOUBLE STATOR SINGLE ROTOR RADIAL FLUX PM GENERATOR

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ABSTRACT

Different Types of generator for wind power usage have become research for many people and researchers. This various generator has been researched for the application of radial flux wind turbines small scale. A double stator single generator has been proposed as an alternative solution in relation to the cost and performance of such systems. However, the greatest emphasis in the report have is the design and performance evaluation of a double stator single rotor radial flux PM generator. The parameter that include in doing the comparisons is frequency, speed ,torque ,current ,voltage and type of motor . Chapter 2 will go through literature a review on past research on this topic. Principles of structure of generator that is axial , radial flux and also with focus on how the generator works by research on the characteristics of the generator with an emphasis on challenges between double stator generator. Different factor of electrical machine that being see is a focus on double stator single rotor configurations, in winding are showed. In Chapter 3, a thoroughly review of the methodology and method which include the method on how to convert or the process of making the motor from single stator to double stator and also testing that need to be test . Next, in chapters 4, an analytical and comparison being done through several test and comparison of the characteristics of the motor between the two type of motor. Studies are validated by comparing the measured value between two type of motor that is single stator and double stator with output power, frequency, voltage and current of the motor being accounted . Based on the results obtained, the speed and voltage that a stator can achieve for a double stator generator will be transform into graph and make a comparison. Lastly in Chapter 5 a conclusion of research that being done will be made

based on result in chapter 4 that have been obtained also recommendation than can be improved in future research

Keywords: Wind Energy Conversion System, fractional concentrated winding, permanent magnet machines, vertical axis wind turbine, permanent magnet generator,

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ABSTRAK

Jenis-jenis yang berbeza untuk penggunaan kuasa angin telah menjadi penyelidikan bagi ramai orang dan penyelidik. Pelbagai generator ini telah dikaji untuk aplikasi turbin angin fluks radial skala kecil. Penjana tunggal stator tunggal telah dicadangkan sebagai penyelesaian alternatif berhubung dengan kos dan prestasi sistem sedemikian. Walau bagaimanapun, penekanan yang paling besar dalam laporan ini ialah penilaian reka bentuk dan prestasi stator dua penggerak radial pemutar radial tunggal. Parameter yang termasuk dalam membuat perbandingan ialah kekerapan, kelajuan, tork, arus, voltan dan jenis motor. Bab 2 akan meneruskan sastera untuk mengkaji semula penyelidikan masa lalu mengenai topik ini. Prinsip struktur penjana yang paksi, fluks radial dan juga memberi tumpuan kepada bagaimana penjana berfungsi dengan penyelidikan mengenai ciri-ciri penjana dengan penekanan kepada cabaran antara penjana stator dua. Faktor lain dari mesin elektrik yang dilihat adalah tumpuan pada konfigurasi pemutar rotor tunggal berganda, dalam penggulungan ditunjukkan. Dalam Bab 3, kajian menyeluruh metodologi dan kaedah yang merangkumi kaedah bagaimana untuk menukar atau proses membuat enjin dari stator tunggal untuk menggandakan stator dan juga ujian yang perlu diuji. Seterusnya, dalam bab 4, analisis dan perbandingan dilakukan melalui beberapa ujian dan perbandingan ciri-ciri motor antara kedua-dua jenis motor. Kajian disahkan dengan membandingkan nilai diukur antara dua jenis motor yang merupakan stator tunggal dan stator dua dengan kuasa output, frekuensi, voltan dan arus motor yang diambil kira. Berdasarkan hasil yang diperoleh, kelajuan dan voltan yang dapat dicapai oleh pemegun untuk penjana stator dua akan diubah menjadi graf dan membuat perbandingan. Terakhir dalam Bab 5 hasil penyelidikan yang akan dilakukan akan berdasarkan hasil dalam bab

Kata kunci: Sistem Penukaran Tenaga Angin, penggulungan berpusat pecahan, mesin magnet kekal, turbin angin paksi menegak, penjana magnet kekal,

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All praise to supreme Almighty Allah swt, the only creator, cherisher, sustainer, and efficient assembler of the world and galaxies whose blessings and kindness have enabled the author to accomplish this project successfully. The author would also like to take this opportunity to thank the guidance, advice, support and encouragement he received from will, Professor Ir. Dr. Abdul Halim Bin Abu Bakar and Dr Che Hang Seng always advise and comment throughout the project until it become a real success. Great appreciation is given to my family and friends for the assistance, advice and encouragement that have been given. In addition, the authors would like to thank on the help and guidance. Appreciation also to the Faculty of Electric to provide facilities and components needed to implement this project.

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LIST OF SYMBOLS AND ABBREVIATIONS

DC	:	Direct current
AC	:	Alternating current
Rpm	:	Revolution per minute
N	:	Speed (rpm)
P	:	Number of pole
N	:	Number of turns for coil winding
PM	:	Permanent magnet
PAM	:	Permeance Analysis Method
FEM	:	Finite Element Method
N	:	North pole
S	:	South pole
2D	:	Two-dimensional
3D	:	Three-dimensional
$\Re$	:	Reluctance (H-1)
P	:	Permeance (H)
L	:	Length (m)
μ	:	Permeability (H/m)
A	:	Area (m2)
g	:	Air gap (m)
r_r	:	Radius rotor (m)
θ	:	Angle (°)
V_{emf}	:	Induced voltage (V)
φ	:	Magnetic flux (Wb)
E_G	:	Generator rms voltage (V)

E_a	:	Armature voltage (V)
L_c	:	Coil inductance (H)
I_a	:	Armature current (A)
P_l	:	Losses power (W)
R_c	:	Coil resistance (Ω)
ε_h	:	Hyteresis coefficient
ε_e	:	Eddy current coefficient
B	:	Magnetic flux density (T)
NdFeB	:	neodymium-iron
B_r	:	Remanence flux density (T)
H_c	:	Coercive force (kA/m)
H_k	:	Magnetic field intensity of the PM at operating point (A/m)
A_m	:	Area of PM (m2)
R_a	:	Armature resistance
V_o	:	Output voltage (V)
X_s	:	Synchronous reactance (Ω)
ρ	:	Coil resistivity (Ω/m)
w_c	:	Width coil (m)
d_c	:	Diameter of coil (m)
φ_l	:	Flux linkage (Wb-turns)
r_{ri}	:	Inner radius of rotor (m)
r_{ro}	:	Outer radius of rotor(m)
σ	:	Distance of PM from the surface of the shaft (m) δ
P_{td}	:	Total permeance for double stator (H)
Θ_c	:	Angle of coil area (rad)
g_o	:	Air gap between outer stator and rotor (m)

gi	:	Air gap between inner stator and rotor in (m)
ri	:	Outer radius of the inner stator in (m)
ro	:	Outer radius of the rotor in (m)
hco	:	High of outer coil in (m)
hci	:	High of inner coil (m)
Vs	:	Source Voltage (V)
C	:	Capacitor (F)

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

Electrical energy is generated by a combination of prime mover and generator. Prime mover will provide external force which is mechanical energy to rotate the generator's shaft. Basic types of prime movers are steam turbines, gas turbines, wind turbines, hydraulic turbines, diesel engines, and internal combustion engines. A generator can also be driven by human strength. Basically, there are three main groups of electric generators which are synchronous, induction, and parametric generator. Synchronous generator is the commonly used type that is compatible with renewable energy resources. A Permanent Magnet generator is one of a synchronous generator and it can be divided into two types which are slot type and slot-less type. The direction of the flux in the PM machines could be either radial or axial according to the flux direction in the air gap. PM generators are found in many applications in wind power generation. The use of PM in construction of electrical machines give a lot of benefit such as the construction work is easy and maintenance required is low since field winding is eliminated. The PM can be surface mounted or exterior and interior or embedded in the generator. The surface-mounted PM machine has magnets at the air gap surface and is liable to damage at high speeds or even in the assembly and fabrication process. The rotor structure for an interior PM rotor will have a smooth rotor design. Thus, windage losses will be equal to or lower than those of conventional induction machines. The major contribution in this study is to design and performance evaluation of a double stator single rotor radial flux pm generator by. In order to determine the capability and characteristic of the PM generator, the effect of various parameters are taking into account such speed, voltage, current and frequency .This parameter will be compare to frequency to see the difference between the two type of generator . While slip will be used to compare the load that a motor can perform to carry when it is increased. After that it will be discussed in chapter 4.

1.1 PROBLEM STATEMENT

Recent research using the single stator electric motor to produce a low and not constant electricity. According to this application, double stator is required because it can produce more electricity at one time compare to single stator, so more electricity can be stored on rechargeable battery on a short time period. The weakness of using battery can be resolved by using a generator. However, the available motor on the market is large, heavy and not suitable for the application. New motor that being design is better because it can solve the problem motor while maintaining the ability of power. Generator suitable for this application must be a small and light because the user must carry generator along with the whole. As a result, portable generator specially designed for this purpose system proposed meet the requirements in terms of size, weight and power capabilities. Generator size depends on the size of the prime mover used. Generator PM proposed not another generator type because it has high efficiency, compact, and has a high power density. In addition, the generator PM has a very simple magnetic structure acceptable to low-cost manufacturing. In addition, it requires low maintenance because it has internal magnetic source. One generator PM phase chosen to reduce the power electronic components used to control and change the energy produced by the generator PM. As a result, the cost of this system can be reduced. Generator PM is also easily in design since the PM used to supply the magnetic flux. So a brush and commutator available in dc not needed.

1.2 SCOPE OF STUDY

For this study there will be several area or topic that will be covered and look up. The area that will be included is based on condition, area, type of motor and construction of the motor. The type of motor that will be using is Permanent magnet brush or brushless, it depends on the use of the motor. Other than that, Criteria that will be considered to look after also is the frequency, speed that will be generated and the load effect on the generator for the type of generator. Application that will be tested on is wind energy system, because not many research that focused on it generator to generate electric. That is the scope that will be covered.

1.3 OBJECTIVES

Considering the importance of preserving the environment using renewable energy source and the negative impact of fossils energy to all living. There is a need to develop alternative energy resources by using wind energy source and generated by double stator permanent magnet generator, The main objectives of this research are as follows:

1. To propose design and performance evaluation of a double stator single rotor radial flux pm generator for wind energy turbine generator in order to increase the power output compared to a bare turbine which will assists the turbine to capture more wind energy.
2. To do a slip test to the generator to determine performance of the generator
3. To analyzed the result of the design and performance evaluation of a double stator single rotor radial flux pm generator.

CHAPTER 2: LITERATURE REVIEW

This topic will discuss literature review on double stator and single rotor generator specifically on PM generator and wind energy system. Besides that, type and structure of generator that have previously investigated and published will be reviewed.

2.1 Overview on Related Research of PM Generator

Generators basically function as a device that convert mechanical energy into electrical energy using electromagnetic principles. The energy conversion method is fundamentally the same in all electric generator or motors. This literature review starts with a general overview of types of generator

2.1.1 Types of Generator

There are multiple varieties of electric motor differentiated by structure and signal type, but are generally based on the same principle, pictures below show the different motors organized by classifying features

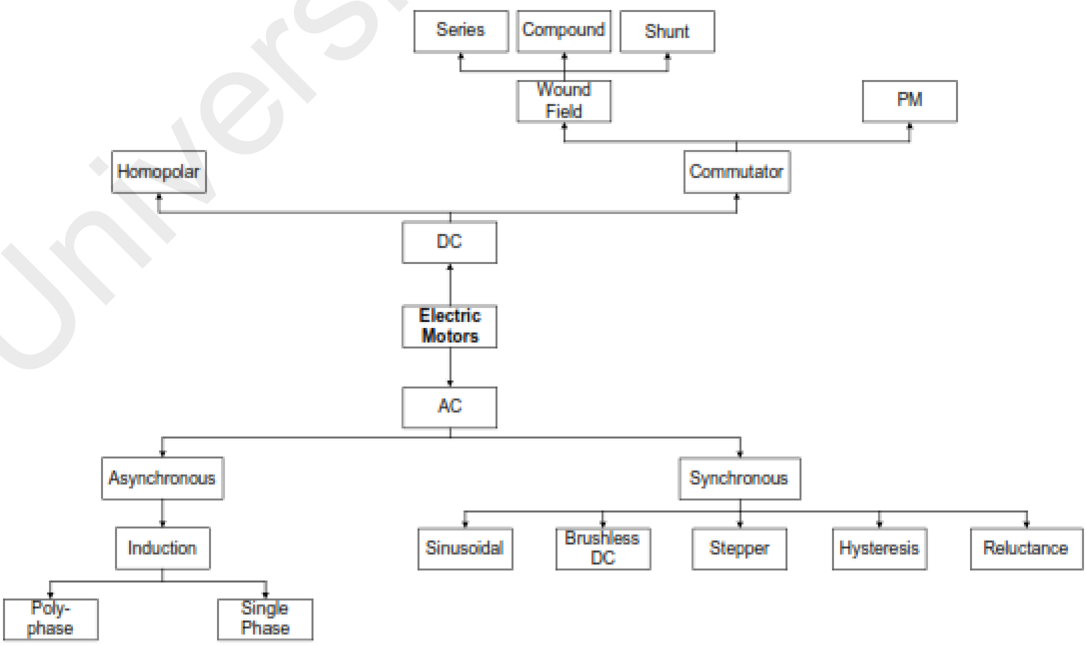


Figure 2.1 Generator Classification

The primary difference between AC and DC motors is the power type applied to the armature. From this vantage, a BLDC motor actually is an AC motor. The difference between an asynchronous and asynchronous motor is whether or not the rotor runs at the same frequency as the stator. Each motor can be used based on specific applications. But in this topic we will be focusing on 2 type of generator that is Induction generator and permanent magnet generator.

2.1.2 Induction Generator

The induction generator is similar to any other generator, as it is a device that converts mechanical energy into electrical energy. An induction generator consists of a rotating element or rotor and a stationary element or stator. The rotor consists of an aluminum or copper 'squirrel cage' within the rotor laminations. The stator consists of insulated copper windings within the stator laminations. Exciter or voltage regulator is not needed in this type of motor. An induction machine (motor or generator) connected to the line power source (excitation) is capable of operating in either mode. If the shaft is allowed to rotate at a speed below synchronous, the machine will attempt to operate as a motor. The rotating magnetic field vector caused by the three phase stator windings will deliver real and reactive power to the rotor as it sweeps around the squirrel cage. If the shaft is forced to rotate at a speed higher than synchronous, the machine will operate as a generator as in figure 2.2. The stator magnetic field vector will continue to deliver reactive power, but now accepts real power induced from the rotor (generator mode). Now the squirrel cage is sweeping the field vector, causing a flux reversal. At synchronous speed, the line supplies reactive power and machine losses, but no torque or power is generated. There is a practical upper limit to the speed at which an induction generator can be operated above synchronous and still generate real power efficiently. This speed is typically 2 to 5 percent above synchronous, but below breakaway torque. Above the breakaway torque speed, the real power generated decays quickly to a low value. There is two type of induction generator, there is squirrel cage induction generator(SCIG) and doubly fed induction generator (DFIG) , that will be explained .

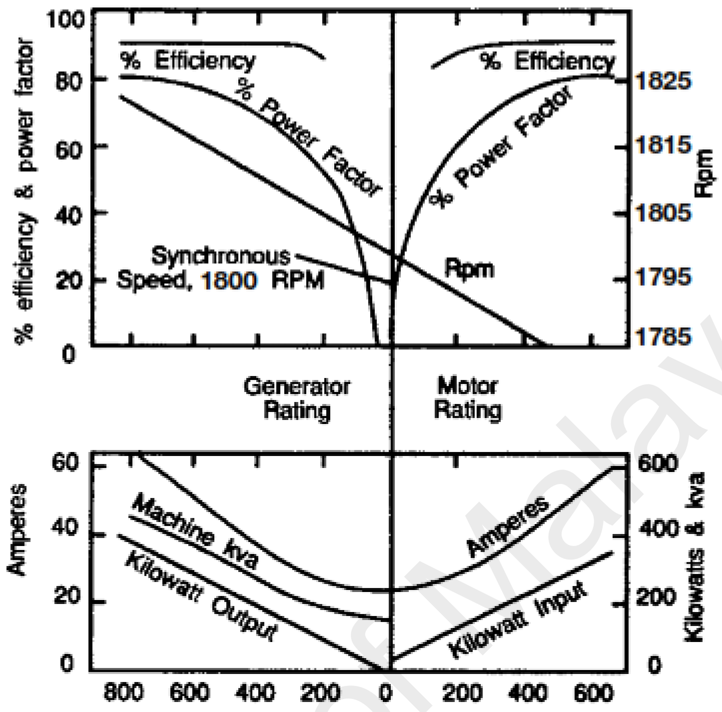


Figure 2.2: Generator and Motor condition

2.1.3 SQUIRREL-CAGE INDUCTION GENERATOR (SCIG)

Three-phase squirrel-cage induction generators are usually implemented in standalone power systems that employ renewable energy resources, like hydropower and wind energy. This is due to the advantages of these generators over conventional synchronous generators. The main advantages are reduced unit cost, absence of a separate DC source for excitation, ruggedness, brushless rotor construction, and ease of maintenance. A three-phase induction machine can be operated as a self-excited induction generator if its rotor is externally driven at a suitable speed, and a three-phase capacitor bank of a sufficient value is connected across its stator terminals. The stator winding in this generation system is connected to the grid through a four-quadrant power converter comprised of two PWM VSI connects back-to-back trough a DC link voltage, this can be shown in Fig. 2.3.

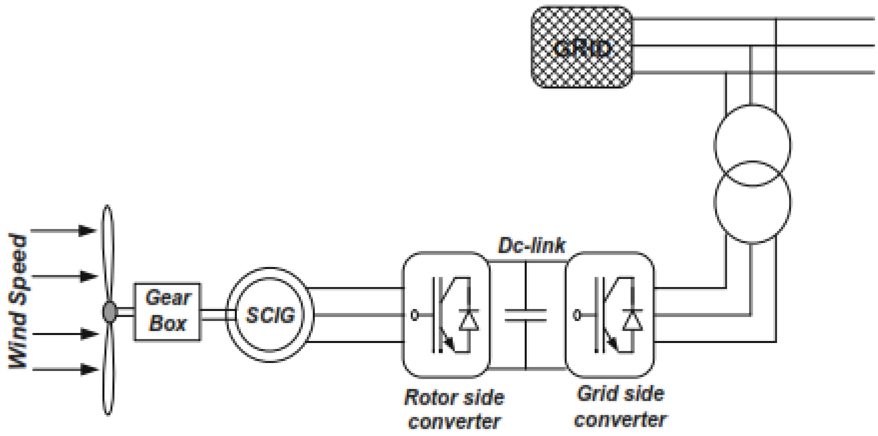


Figure 2.3 : Squirrel-cage induction generator (SCIG) driven by a wind turbine

The control system of the stator side converter regulates the electromagnetic torque and supplies the reactive power to maintain the machine magnetized. The supply side converter regulates the real and reactive power delivered from the system to the utility and regulates the DC link, but the uses of SCIG have some drawbacks as following [8]: Complex system control, whose performance is dependent on the good knowledge of the generator parameter that varies with magnetic saturation, temperature, and frequency. The stator side converter must be oversized 30–50% with respect to rated power, in order to supply the magnetizing requirement of the machine.

2.1.4 Doubly-fed Induction Generator (DFIG)

Doubly-fed Induction Generator (DFIG) is rotor windings that are connected to the grid through slip rings and back-to-back voltage source converter that controls both the rotor and the grid currents. The active and reactive power can be control by using converter to control the rotor currents. There are a lot of advantages over a conventional induction machine in wind power applications. First the induction generator is able to import and export reactive power. This is important for power system stability and allows the machine to support the grid during severe voltage disturbances (low voltage ride through, LVRT). Second, it is make the induction machine to synchronized with the grid while the wind turbine speed varies. A variable speed wind turbine makes use the available wind resource more efficiently than a fixed speed wind turbine, especially during light wind conditions. Third, the cost of the converter is low when compared with other variable speed solutions because only a fraction of the mechanical power, typically 25-30%, is fed to the grid through the converter, the rest being fed to grid directly from the stator and improve the efficiency.

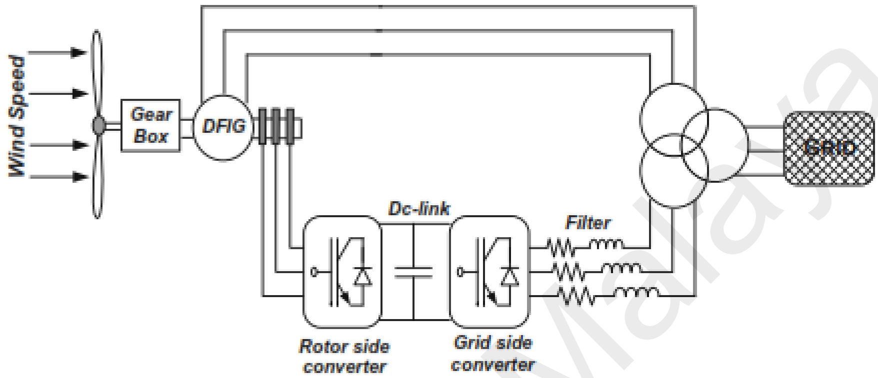
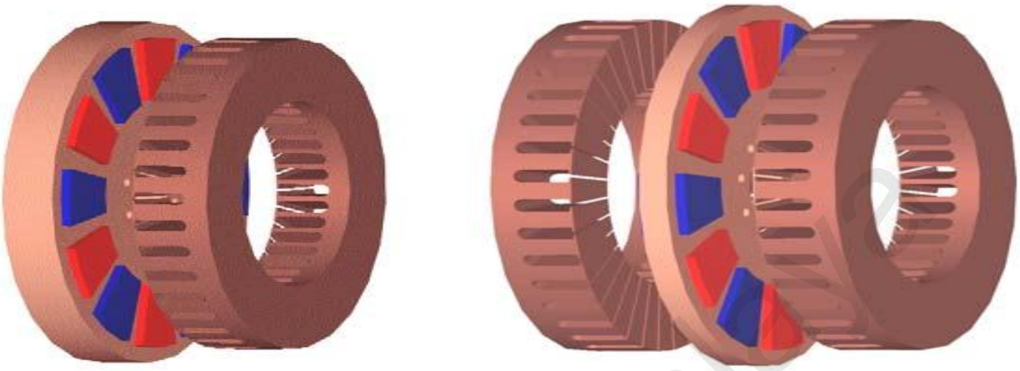


Figure 2.4 : Doubly Fed wound rotor induction generator driven by a wind turbine

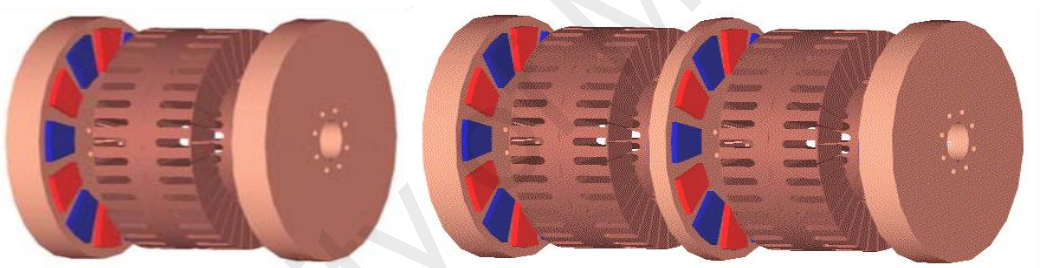
There is a lot of research that have been done by previous researcher regarding this type of generator . First researcher is Pablo Ledesma et al. suggested a DFIG model which useful for the study of transient stability. This model has taken into account two assumptions that is Electromagnetic transients in the branch linking the grid & inverters and stator are neglected, next assumptions is by neglecting the current control loop dynamics, the current control can be taken into account as instantaneous value. MATLAB software is used for the study [9]. Istvan Erlich et al. [10] studied the DFIG modeling and modelling of converters for stability analysis. A reduced order model of DFIG is developed to facilitate proficient computation, which limits the calculation of the fundamental component of frequency. In this paper improved model is presented which allows to consider the alternating component of rotor current, that is essential for initiation of the crowbar operation. Various appropriate models of RSCs and GSCs in addition to dc-link is presented which has considered all four possible modes of operation. For studies of power system simulation, the model which is presented is useful. Andreas et al. [11] presented an alternative approach to obtain third-order model for DFIG as well as introduced the possibility to develop a model of rotor circuit's voltage sources that can be useful for simulation of several generating methods, like variable-speed WECS. The goal of this report is to get a set of some simplified equations as compared to which are commonly used. To make the dynamic simulation of DFIG easier a model is presented in this paper. An extension [m3] in which DC-components of stator are ignored with not ever-increasing the modelling and simulation efforts significantly has been presented in [12]. Simulation results, which explain the performance of DFIG and is related control systems during fault conditions are also provided in this paper. In this publication, modelling of the grid is done by algebraic equations so that we can get better simulation results than the alternative calculations of instantaneous values based on full order models for both grid as well as DFIG. In [13], the steady-state behavior of DFIG based WECS in MATLAB has been analyzed. Various characteristics of DFIG, including real and reactive-power over speed and torque-speed characteristics simulation is done. From the simulation results, the operating characteristics of DFIG are examined. From simulation results, it can be clearly said that by injecting rotor voltage of DFIG, its characteristics are affected. The overall modelling and simulation of DFIG based WTS which is attached with the grid has been reported in [14]. Modelling and simulation of complete system is done in MATAB/Simulink such that it may become suitable for modelling and simulation of various configurations type of induction generator [14] The dynamic performance of grid connected DFIG based WT with the occurrence of disturbances has been presented in reference [15]. In which for studying the WTG response to voltage sags, frequency control, voltage control and variations of wind, DFIG model has been presented and used. In [16], Ekanayake et al. investigated that accurate models of generator are required for analyzing the influence of installation of DFIG on operation and control of power system. A third and fifth order generator models have been illustrated and WT control is studied in this research paper. The functioning of DFIG during network fault is also studied. In [17, 18], by neglecting the DFIG's stator flux dynamics, a third order model is suggested which offers a correct mean value [16] however some of the DFIG main dynamics are also neglected. Zhenhua Jiang et al. [19], added up the energy storage system to the DFIG based WTS, owing to the irregularity of power generation through wind. With a bi-directional DC/DC power converter in DFIG based WTS, a battery is provided to the DC link of converters. To get the smooth output power with wind variations, the energy storage device can be controlled.

2.1.5 Axial Flux Permanent magnet (AFPM)

Axial Flux is one of the type of configuration in permanent magnet, it happens when the lines of magnetic flux that passed through the coils of wire, travel along the "axis" of the turning motion. AFPM motors can be designed as double sided or single sided machines, with or without armature slots, with internal or external rotors and with surface mounted or interior type permanent magnets (PMs). Low power AFPM machines are usually machines with slot less windings and the surface mounted PMs. Rotors are embedded in power transmission components to optimize the volume, mass, power transfer and assembly time [37] .



(a) Single-sided AFPM motor (b) double-sided AFPM motor with internal rotor,



(c) double-sided AFPM motor with external rotors (d) multi stack AFPM motors [38]

Figure 2.5 : AFPM Configurations

Double-sided motor with internal PM disc rotor has the armature windings located on the two stator cores. The disc with the PM rotates between the two stators .PMs are embedded or glued in a non ferromagnetic rotor skeleton. When the stators are connected in parallel the motor can operate even when one stator windings break down. The stator cores are wounded from electro technical steel strips and the slots are machined by shaping or planning [39, 40]. Several axial-flux machine configurations can be found regarding the stator(s) position with respect to the rotor(s) positions and the winding arrangements giving freedoms to select the most suitable machine structure into the considered application. Possible configurations are shown in Figure. 2.5.

Another common type of AFPM motor is torus type motor which has found numerous applications, in particular, in gearless drives for electrical vehicles. It resembles the motor shown in Figure.2.5.c. The stator however has slot less core and the Gramme' s type winding [41, 42]. The stator core is made of laminated iron. The rotor discs are made of solid iron contain the high energy permanent magnets glued to their surfaces. Double-sided AFPM motor with one stator, which is an object of this study, is shown in Figure. 2.5 [43, 44]. It is more compact than the motor with internal rotor. The double-sided rotor with PMs is located at the two sides of the stator. The stator consists of the electromagnetic elements made of ferromagnetic cores and coils wound on them. These elements are placed axially and uniformly distributed on the stator circumference and glued together by means of synthetic resin. The particular motor with the dimensions shown in Figure. 2.6 was designed as an integrated water pump [45]. The stator coils can be connected in single-phase and multi-phase systems. The motor of particular winding connection exhibits its unique performance that differs it from the motors of the other connection systems.

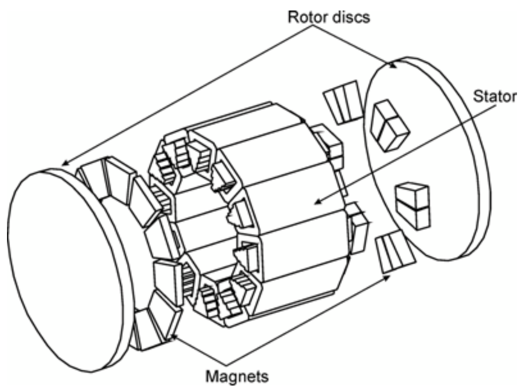


Figure 2.6 : Scheme of double sided motor with one stator is considered in this project [46]

2.1.6 Radial Flux Permanent Magnet

In most motors, flux crosses from the rotor to the stator in the radial direction. This type of motors has an inner rotor and outer stator. Figure 2.7 shows a variety of the most common inner rotor types. The type of inner rotor that will be using in this project is the Figure. 2.7 e

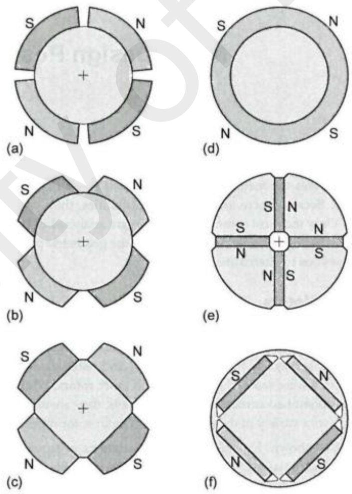


Figure 2.7 : Type of Rotor

The rotor shown in Fig.2.7 e is known as the spoke configuration. This configuration is flux concentration because the magnet surface area is greater than the rotor surface area. This rotor type is good for gaining better performance from ferrite magnet material and has the benefit of using rectangular block magnets. It is commonly assumed that the shape of a magnet determines the direction of its magnetization. Stators for inner rotor motors appear in two general forms. Basically, the stator can be slotted or slot less as shown in Figures. 2.8a and 2.8b respectively.

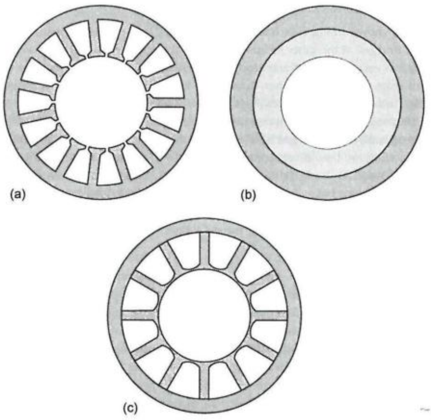


Figure 2.8 : Type of Stator

The slotted stator has a small magnetic air gap making air gap flux density greater. Cogging torque and the cost of inserting windings through small slot openings are the disadvantages of the slotted stator. In the slot less stator as shown in Figures 2.8b, windings are formed into a ring that fits inside the stator yoke and separated from the rotor by a small physical air gap. This construction exhibits no cogging torque since the reluctance seen by the rotor magnets does not vary with position. The stator shown in Figures. 2.8 c has no slot openings.

For outer rotor, motors it can be seen in spindle motors for hard disk drives and as the drive motor for ventilation fans, such as those used to cool CPUs and computer cases. An outer rotor motor has a much larger air gap radius than that of an inner rotor motor. As a result, higher torque is achievable, provided the ohmic losses the stator windings can be dissipated.

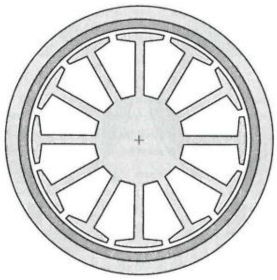


Figure 2.9 : Cross section of outer rotor

2.2 Double Stator Single Rotor

Double stator topology has been widely used in motors for different applications where power segmentation and reliability are main concern. Dual stator configurations are already being used in induction, synchronous motors for applications like wind-mill generators, aircrafts, electric vehicles and automation. The new double stator permanent magnet motor synchronous motor concept is proposed for integration in an electric vehicle, in order to increase the viability, flexibility and high level of precision and system control due to higher electromagnet is useful torque, comparing to a standard permanent magnet synchronous motor . As any electrical machine, a double stator permanent magnet synchronous motor is mainly composed by two principle components, the fixed and non-fixed, respectively designated the stator and the rotor. The source of the electromagnet is flux is a set of high performance permanent magnet that is installed on the rotor surface, or inside it. The magnetic interaction between the stator and rotor field will result in electromagnetic useful torque. This torque will be responsible to drive the entire mechanical component composed by the rotor, the transmission axle, the wheels and the external load. In these dual stator machines, there are two stator windings that is inner winding and outer winding. with the inside winding smaller that the outer which share the same magnetic and mechanical structures. These machines are typically used in high power applications. The stators may consist of two identical windings with or without phase shift . The two windings may have different number of poles, number of phases and ratings. In dual stator machine, the output torque corresponds to the algebraic sum of two independent torques. In terms of construction, there are two air gaps instead of one as the conventional motor, because the rotor is positioned between the outer between the outer and inner stator. It has the advantage that currents of both the inner and outer stators produce electromagnetic torque and there are two air-gaps to deliver the output torque, thus improving the torque density.

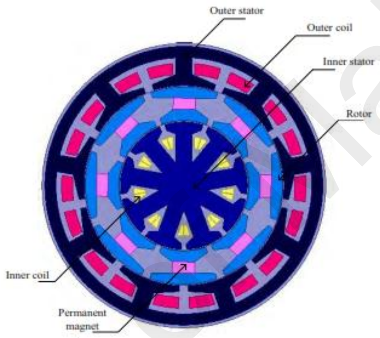


Figure 2.10 : Basic structure of permanent magnet motor

2.2.1 Comparison of single and double stator permanent magnet motor

The main difference is the single stator permanent magnet motor has only single stator and single rotor while the double stator permanent magnet has two stators which is inner stator and outer stator and single rotor. Beside that the single stator only has one air gap but the double stator has two air gaps. Based on the research, when the double stator has two stators, the torque produced will be higher compared to the single stator. This is because both outer and inner stator can produce electromagnetic torque and there are two air gaps to deliver the output torque that will be improving the torque density.

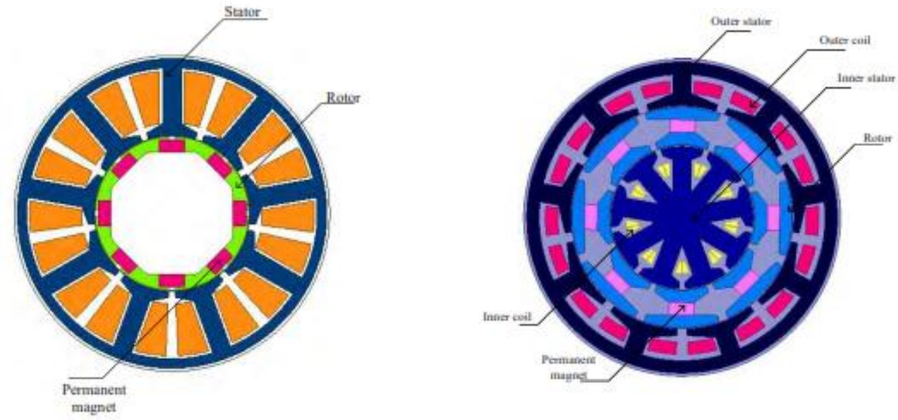


Figure 2.11 : The basic structure of Single Stator and Double Stator Permanent Magnet Motor

2.2.2 Configuration of the Double Stator Permanent Magnet Motor

This motor consists of double stator which is inner and outer stator and a single rotor. This DSPMM consists of 9 slot 8 pole configurations. The DSPMM is designed in three phase system and outer and inner is connected in series. In the structure of double stator permanent magnet motor, the rotor with permanent magnet located in the middle of the motor and the Inner Stator Rotor

CHAPTER 3: METHODOLOGY

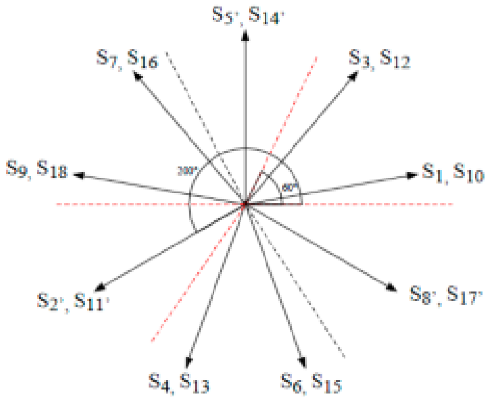
3.1 Method on How to do conversion

In this chapter, a research methodology on how to do a design and performance evaluation of a double stator single rotor radial flux PM generator and detailed information about the testing that will be done to both type of generators.

For a conversion to be done, a two pole pair permanent magnet generator is needed to be convert into double stator single rotor generator. First the motor that being selected is tested and inspected for any defect to make sure it working and can be used for testing. Then starting to unscrew all screw that attached to the casing of generator. Before removing the casing, slowly open the casing to make sure no wire or winding that connected, remove it .

Figure 3.1 : Conversion To DSSR

Next located the rotor, because the rotor need to be removed, to make sure the second winding can be slotted in between the existing winding and the rotor . After that find the second winding that fit in between existing winding and the rotor also have enough air gap and not contacted from each other to avoid short circuit.



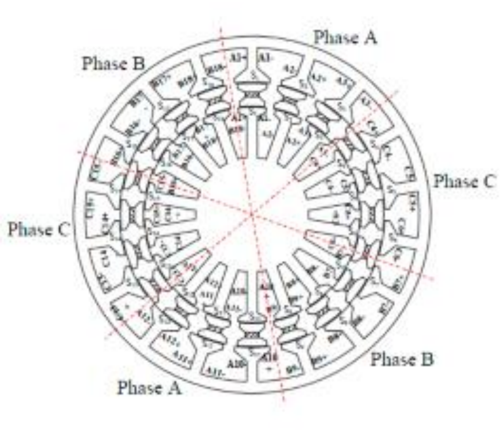


Figure 3.2 : Coil Vectors **Figure 3.3 : Winding Arrangement**

When all is fitted in in place, a connection according to polarity between 1st winding and 2nd winding can be made in series connection. Star Of Slots method is used to find the winding layout for DSSR-PMG. The coil vector arrangement is based on the electrical degree of the electromotive force (EMF) induced in the coil side of each slot. Figure 3.2 & 3.3 shows the coil vectors and winding arrangement of DSSR-PMG where S means slot number inside the generator. Each phase has four coils connected in series. The phasor inside in the same sector belongs to the same phase as in Figure 3.2. For phase A, the vector numbers with S1, S2 , S3 , S10 , S11, and S12 are in one sector. Since S2 and S11 are in opposite direction, the coil are in negative polarity. The same process is process is applied to phase B. Each phase encompasses six slots with four slots in positive and the other two with negative polarity. The winding arrangement for the inner and outer stator of DSSR-PMG is shown in Figure3.3. The details phase and coil arrangements for DSSR-PMG are listed in Table 3.1.

PHASE	POSITIVE	NEGATIVE
A	S1,S10,S3,12	S2,S11
B	S7,S9,S16,S18	S8,S17
C	S4,S6,S13,S15	S4,S14

Table 3.1 : DSSR-PMG coil arrangements.

Lastly assemble back the cover and all parts that have been removed in its place, the generator than can be put for testing.

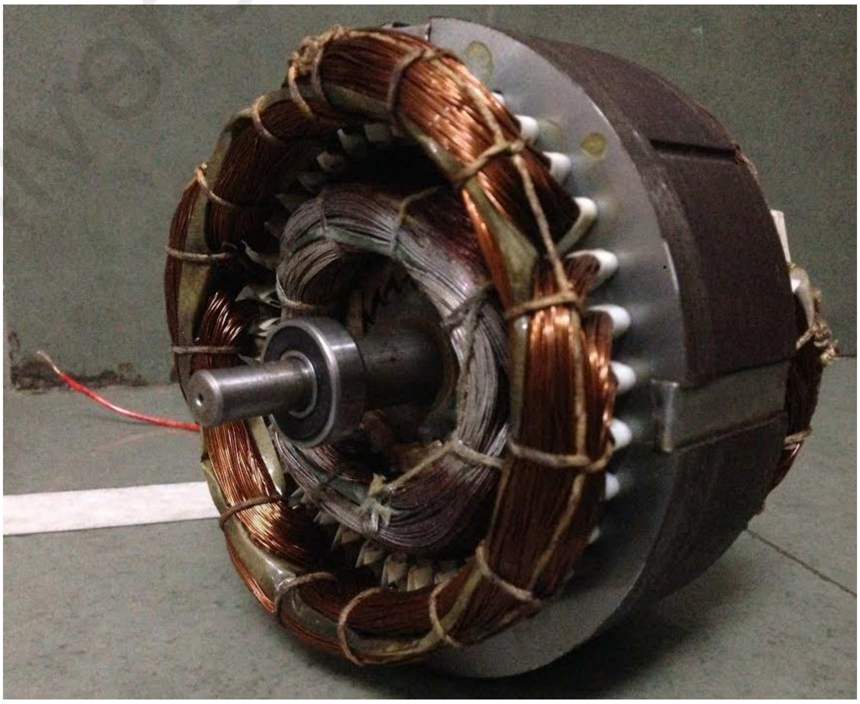


Figure 3.4 : Permanent magnet induction generator

3.2 Generator Performance Evaluation

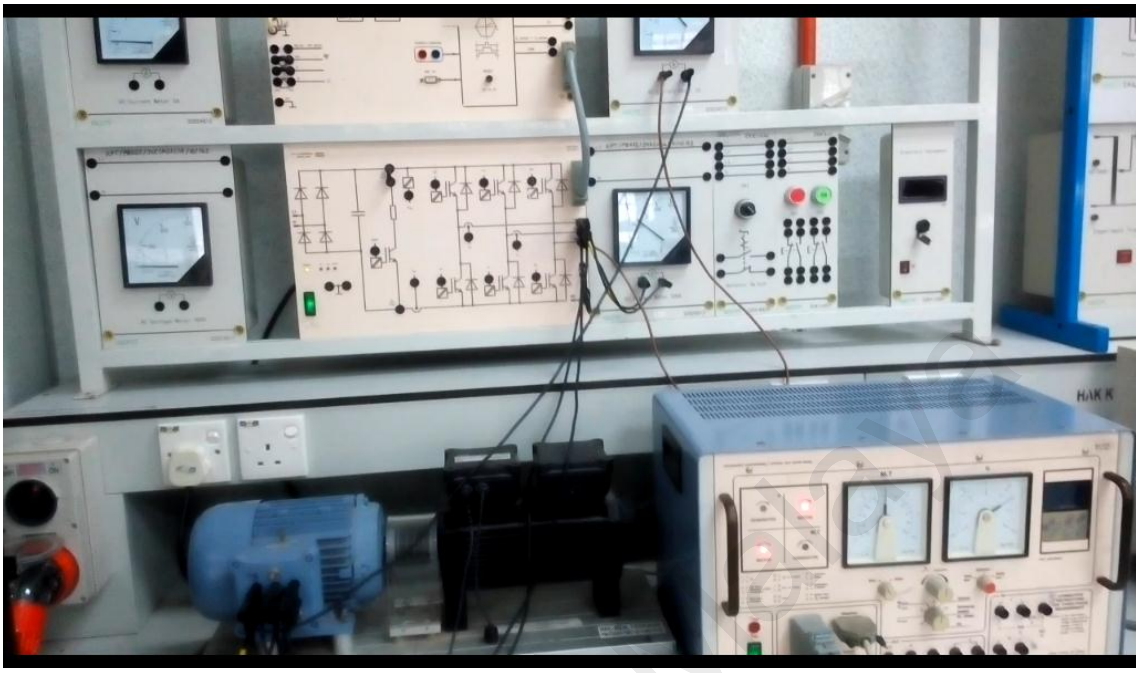


Figure 3.5 : Generator Set up for data collection

First step on doing this performance evaluation of a Double stator single rotor (DSSR) is to get the reading of the existing single rotor generator before the modification. To get the reading we used a Single rotor permanent magnet generator to get the default reading and also to know the characteristic curves of the generator vary with the frequency. The equipment that required in this testing is frequency inverter control and power unit, pendulum machine , brake control ,3 phase PMG , brake control , ammeter and voltmeter to measure the current ,voltage. .

Once all the equipment has been ready, a connection from pendulum machine and the generator with help of coupling collar can be made. Next is connect the brake control unit to generator and make the setting rotational frequency range to 3000 rpm.

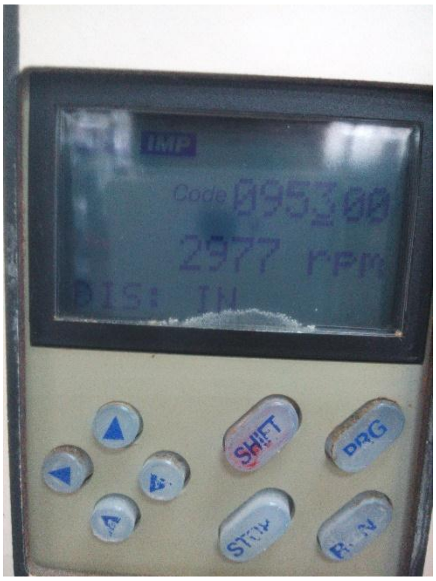


Figure 3.6 : Speed Meter

After all the connection have been made, frequency inverter control and power unit need to be turn on, with the frequency inverter should be adjustable between 0hz and 100hz .

Figure 3.7 : Frequency Setting

The acceleration and deceleration of the generator need to be as immediate as possible when the frequency setting is changed. Lastly after all the parameters at the interface operator have been made the reading for the speed, voltage, current can be collect for the generator.

Figure 3.8 : Ammeter

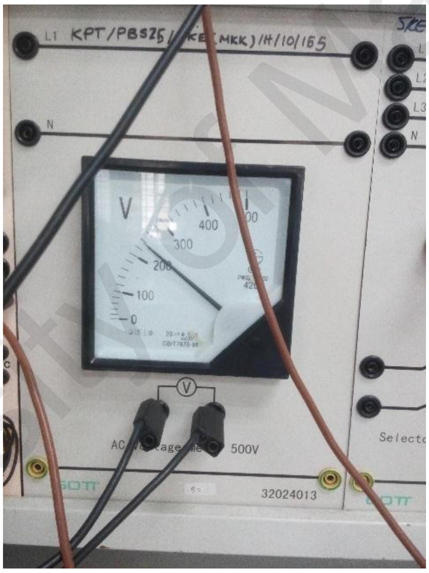


Figure 3.9 : Voltmeter

Then after finish collecting data needed, same step will be repeated back but with different generator type, that is (DSSR) and the result, comparison , and discussion will be discuss in next chapter .

3.3 Slip Test

Slip test is one of the test that being done to two type of motor that being tested. It is a procedure to find the ratio of direct axis reactance(xd) to quadrature axis reactance (xq) . It is done by rotor of the alternator being rotate by an external prime mover (usually a dc motor) while rotor windings of the alternator are kept open and also voltage must less than the rated voltage. An excitation is applying to the field winding and voltage gets induced in the armature. The circuit diagram is shown in the Fig. 3.10

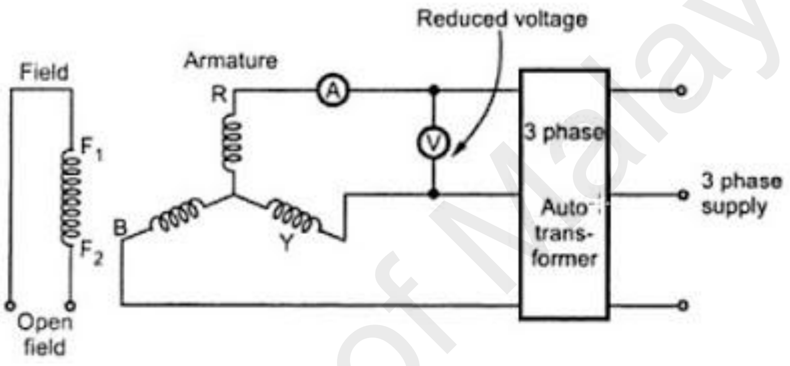


Figure 3.10 : Circuit Diagram For slip test

The alternator is run at a speed close to synchronous but little less than synchronous value. The three phase currents drawn by the armature from a three phase supply produce a rotating flux. Thus the armature m.m.f. wave is rotating at synchronous speed as shown in the Fig. 3.11.

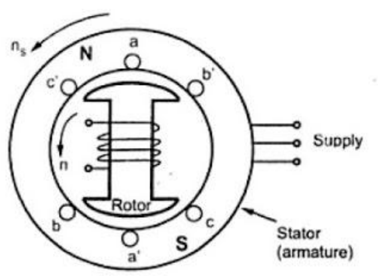


Figure 3.11 : Synchronous Speed

The armature is stationary, but the flux and hence m.m.f. wave produced by three phase armature currents is rotating. This is similar to the rotating magnetic field existing in an induction motor.The rotor is made to rotate at a speed little less than the synchronous speed. Thus armature m.m.f. having synchronous speed, moves slowly past the filed poles at a slip speed (ns -n) where n is actual speed of rotor. This causes an e.m.f. to be induced in the field circuit.When the stator m.m.f. is aligned with the d-axis effective reactance offered by the alternator is Xd.and also when the stator m.m.f. is aligned with the q-axis of effective reactance offered by the alternator is Xq.As the air gap is non uniform, the reactance offered also varies and hence current drawn the armature also varies cyclically at twice the slip frequency.

3.4 Slip Test Testing

The setup of equipment to get the result for slip test is the same as the step to do a comparison between two generator, The different is setting in the experimental panel system , specifically to the frequency inverter setting need to be change from 0 -2.5 slip composition , than the result of speed being recorded . Other than that setting it is the same as before.

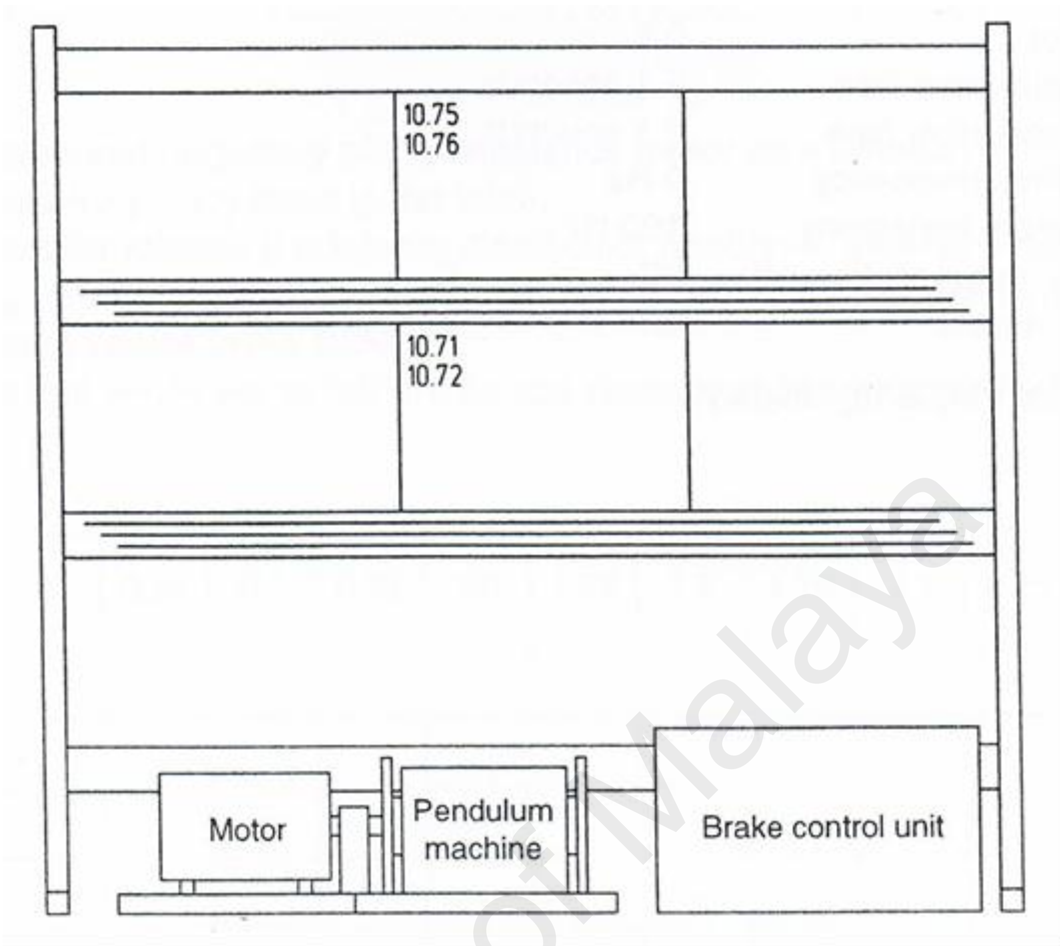


Figure 3.12 : Slip test Set up

CHAPTER 4: RESULT AND DISCUSSION

4.1 Results and analysis

In this chapter will analyzing the result of the design and performance evaluation of a double stator single rotor The speed ratio based optimal tip is analyzed in this chapter. Two type of generator that is single and double stator PMSG are analyzed and compared. Then, the results of the generator-side converter control are compare. There are various studies done on comparison of these two type generator topologies. In this chapter two type of generator are compared in terms of frequency, speed, voltage and current. The result will be discussed based on graph that have been obtained from testing that have been done in chapter 3.

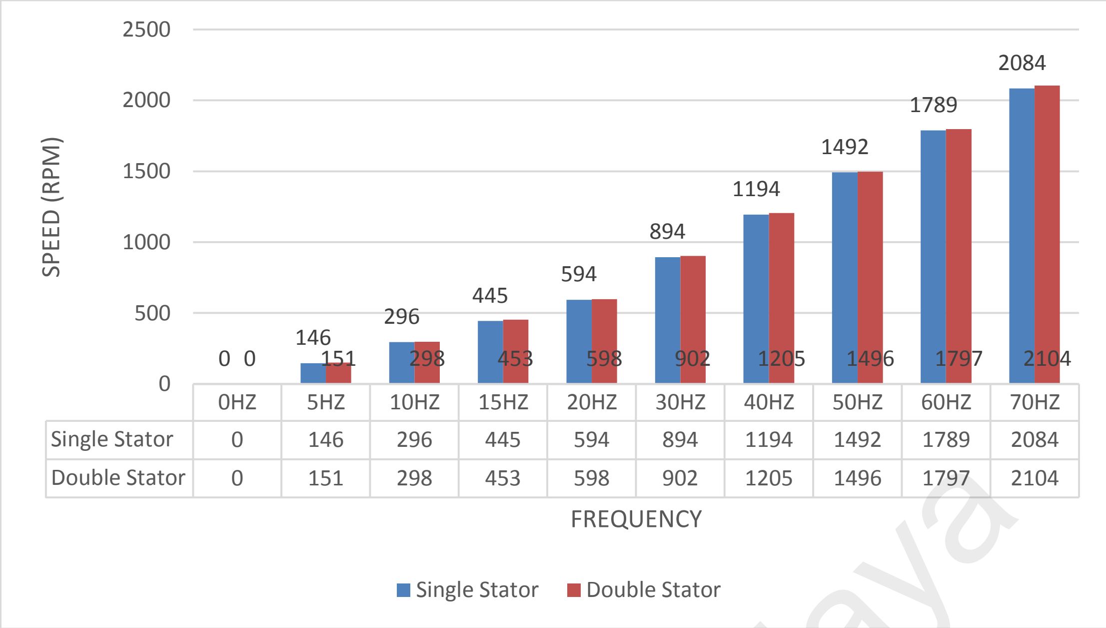


Figure 4.1 : Speed vs Frequency

The experiment results shown on figure 4.1 to 4.3 . Figure 4.1 shows comparison speed of two type of generator at different type of frequency from 0 until 70 Hz. Can be seen in these graph , from 0-70Hz s, The generator speed constantly increased from 146 rpm to 2084 rpm. In this generator speed range, we can investigate the performance between Double Stator Single Rotor (DSSR) to Single stator single rotor (SSSR) . Value from 0-40 Hz , is the frequency that under the rated frequency so the speed is slow and 50 Hz is the rated frequency for the generator .Shown that this generator can go up to 70Hz after rated value , this is based on the maximum range that being set on brake control unit frequency meter .

In term of speed between the two type of generator, there is a slight increase in the value of speed from 0 – 70Hz , the difference between two type of generator speed is only in small value from 3-10 rpm . the system performance in a given value can be assessed. But after the rated frequency of 50Hz , the increased of the speed is a bit higher up to 10 rpm , this could be because the speed after 50 hz is not being monitor during production ,also not recommended by manufacturer and can damage the generator

Shown in Figure 4.2 is the generated output voltage of two generators in an electric controlled by frequency. It can be seen that it increase from 0 to maximum 242V and frequency up to 70 hz . Also the generated value not very difference between two type of generator.

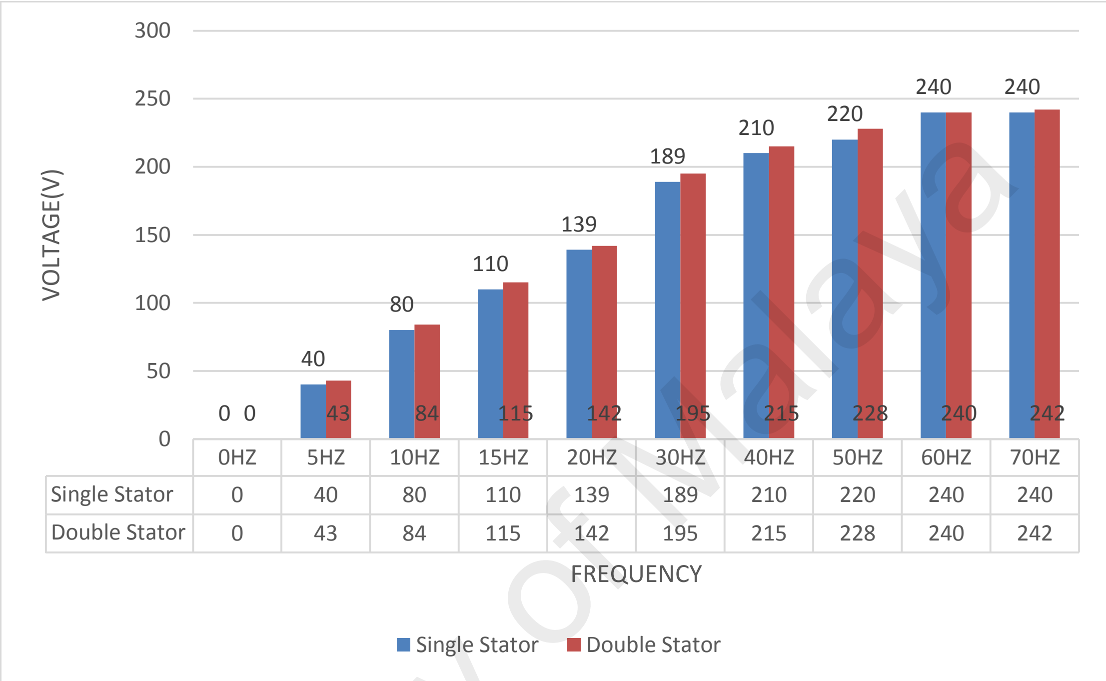


Figure 4.2 : Voltage vs Frequency

As can be seen in the simulation results, according to different selection of frequency, the voltage had increase consistently for the two type of generator, after 50Hz the voltage stops increasing, soon after that the system comes to the steady state and consistent until the end. This could be happening because of the generator have been design for rated voltage of between 220-240V so it will increase even though the frequency being adjusted.

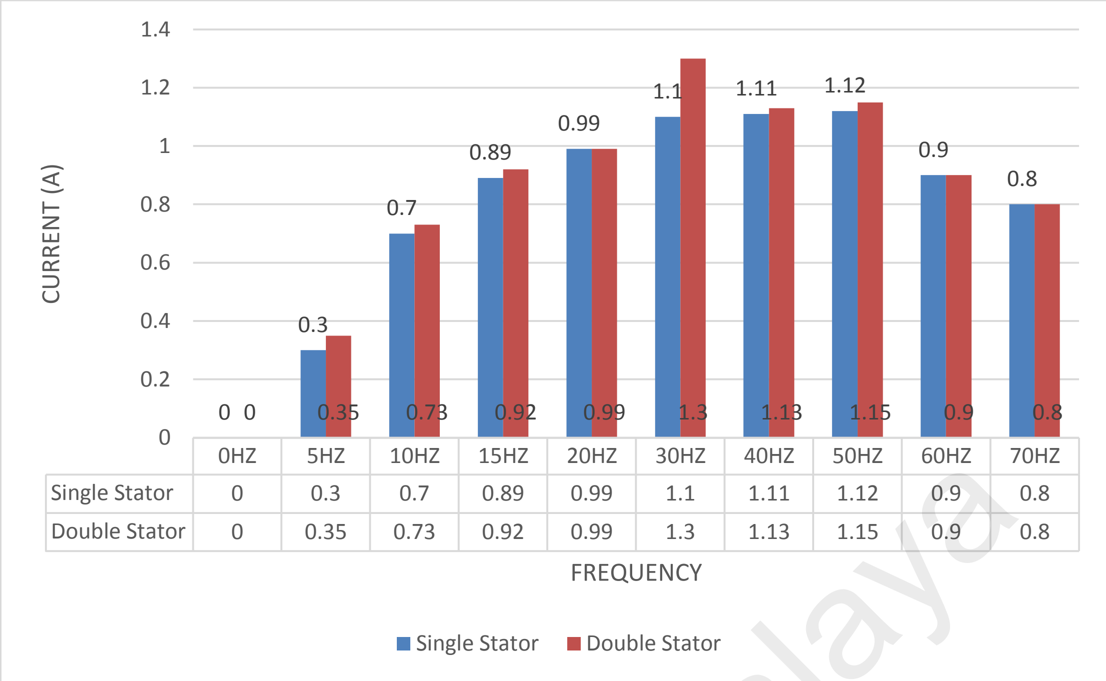


Figure 4.3 : Current vs Frequency

The graph above shown, result of current with different frequency range, It can be seen that the current have increase drastically from 5Hz to 10 Hz, and after that it is almost consistent the value increasing. Until after 50 Hz the current back to decreasing because the frequency is over the rated current setting .This condition happen to both type of generator .

4.2 Slip Test

The goal of the test program is to determine the performance features of the generator. A difference value of slip or load have been set to see any affect that can happen to the generator. This test has been done to both type of generator. The generator was tested at a number of slip and frequency points. A number of data points were taken within the specified frequency and speed values. The data from the test is shown below in Tables and plotted in Figures 4.4 -4.6 .

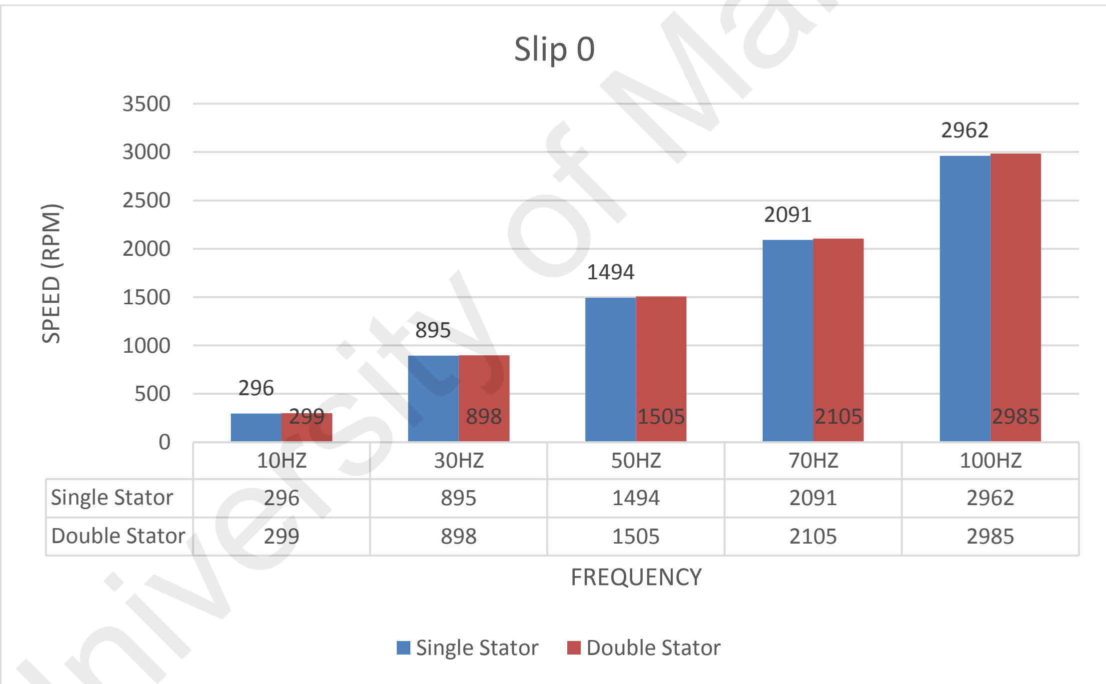


Figure 4.4 : Slip 0

From Figure 5, the maximum speed developed by the generator over the frequency range tested was about 2962 rpm. This result is when there is not in any slip or load condition. So the generator or motor is rotate with no burden.

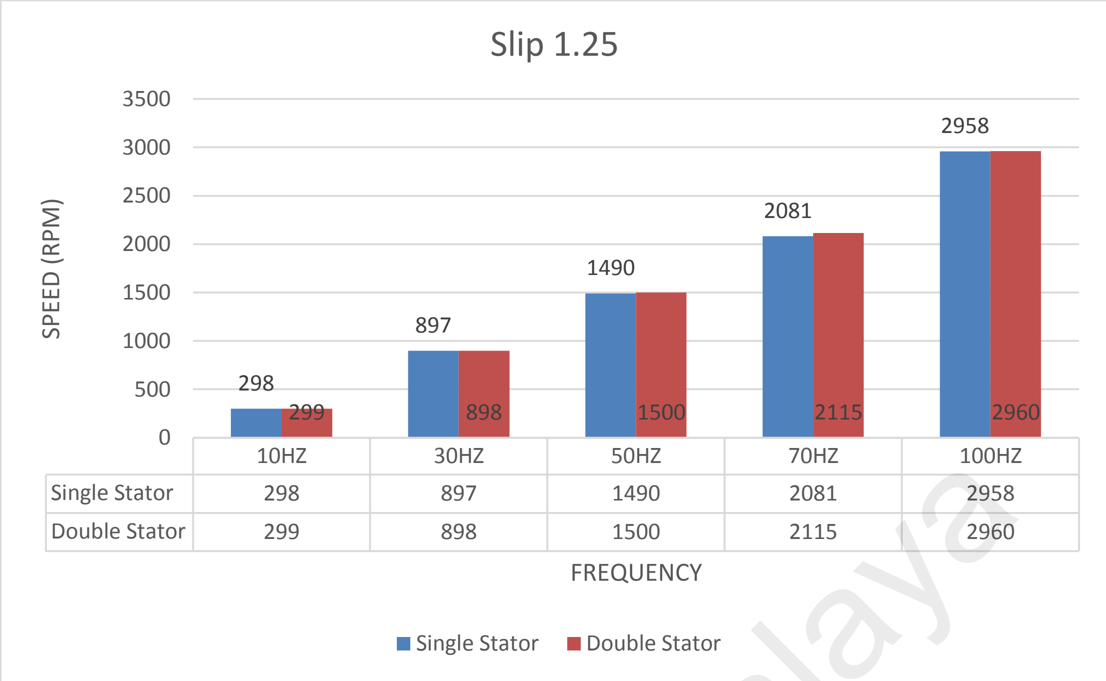
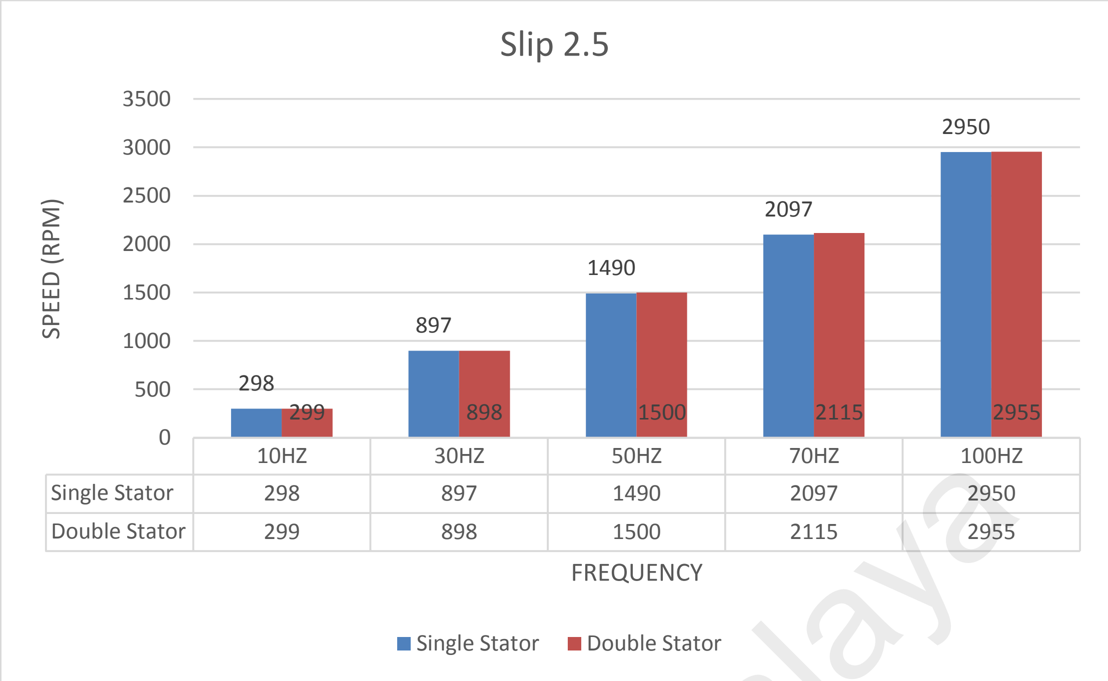


Figure 4.5 : Slip 1.25

After that in figure the motor has been add with a 1.25 slip load to monitor the condition, and from the graph can be seen that the value of motor speed have decrease in small value from figure. With the maximum speed have been reduced to 2958rpm at 100 Hz.



	10HZ	30HZ	50HZ	70HZ	100HZ
Single Stator	298	897	1490	2097	2950
Double Stator	299	898	1500	2115	2955

Figure 4.6 : Slip 2.5

For the last result in figure the slip or load have been increased to 2.5. From the result also can be seen that Also the maximum speed have reduced to 2950rpm and it is achieved within the tested load points .From all this slip test that have been done we can say that the difference between the two type generator is not very high with multi type of slip.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the experiment, research and test that have been done on the two type of generator, it can be concluded that from this research that the double stator single generator still are not in optimum condition to be used as a charging motor and application on wind turbine application because the output generation are still not stable and have nearly the same result with single stator generator, a further study on this case need to be done in the future

For the slip test the speed and performance that have been done to the generator, shows a significant finding with the measured data. The test has been done at three condition of slip that is 0, 1.5and 1.25. The findings show that for DSSR, the maximum speed that can be reached with this generator is approximately at rotational speeds of 2955 RPM based on graph at load or slip of 2.5.

Lastly for analyzing the result of the optimization double stator , the finding show that at certain load the generator will slow and no output be produce , The assumption made, in this situation because of the 2nd winding that is being installed is not in good condition or not compatible with the existing winding and rotor for generating flux.

5.2 Recommendations

Based on experiment and test that have been done, this project can be further research on its design. Specifically, on position of the stator being located, so that a better output can be generated by good angle of flux cutting. Next is no of pole can be increases more so that in 1 round of circled the rotor will be cutting more pole and generated more electric. Other than that is the weight and size of the generator could be reduced more so it can be portable and easy to handle. For future development, instead of rewinding the generator, improving the rotor design can be considered. the rotor may produce the same mechanical power with a smaller diameter. Keeping the design value of the tip-speed ratio constant, this results in higher RPM's so that a smaller transmission ratio is required, which improves the overall efficiency. An added advantage is that the cost of the rotor is reduced because less material is required.

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